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# A REAL LIFE 'THIS OLD HOUSE' STORY, DOD STYLE

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## INTRODUCTION

Renovating the Pentagon is no ordinary rehabilitation assignment; it is a mission to salvage and modernize one of the engineering marvels of the 20th century. This mammoth project will replace outdated mechanical and electrical systems in the 55+ year old landmark with reliable, energy-efficient equipment. The entire project, which began in 1990, will take about 15 years to complete, and is estimated to cost slightly over $1 billion.

The Pentagon presents a daunting array of challenges to any renovation project, including: existing major mechanical and operational defects, outdated electrical wiring and equipment, and insufficient electrical capacity to meet the demand of a late 20th-century office environment. Windows which must be preserved due to their historical value to the building, and the need for replacement and installation of functional windows for the regulation of ambient daylight. There is also the issue of the lack of adequate vertical transportation which needed to be addressed.

A large number of additional constraints associated with this particular site significantly impact the project. Among these are: structural issues, groundwater issues, and highways which pass close by the building. Heating and cooling solutions are complicated by the fact that the Potomac River is neither deep nor cool enough to be considered as a resource. Also, Washington National Airport is situated in close proximity to the Pentagon site precludes the option of using cooling towers for the heating and refrigeration plant. The height of such towers would present so close to the flight paths of approaching aircraft.

Adding to the challenges of the project mentioned above, are the requirements that the building remain open while the critical Department of Defense Headquarters Command and Control operations are being performed, it is vital that military operations are kept intact even as the renovation proceeds.

The Pentagon is the world's largest low-rise structure. It houses about 25,000 office workers and contains 28 kilometers (17.5 miles) of corridors. Its 613,133 square meters (6.6 million square feet) of floor space is three times larger than that of the Empire State Building. The structural elements of the five-story historically registered landmark are sound and will require minimal cleaning and preservation. But time has taken its toll on the interior, especially on the electrical and mechanical systems.

This paper discusses some of the lessons learned, major electrical and mechanical in the renovation design and highlights several of the design concepts developed by the renovation team. It is important to emphasize at the outset, that a master plan had been previously developed which included many design details which were ultimately changed in the final designs, resulting in a significant coordination effort by the Renovation Team. The key team members include the Washington Headquarters Service (WHS) (the DOD real estate building manager); the Army Information Systems Command (ISC-IMET (Information Management & Telecommunications), (the communications systems renovator); numerous design and construction firms which will be identified with their respective contributions below; and the U.S. Army Corps of Engineers.

**ELECTRICAL SYSTEMS**

The Pentagon's electrical system performed admirably over the past 50 years, but it was not designed to keep pace with the demands of today's high-tech environment, with its computers, printers, copying machines and fax machines. As a result, it is not uncommon for the Pentagon to experience 30 to 40 localized power outages each day. Here are several components of the electrical infrastructure that needed to be addressed:

**Network Transformers** – the original Pentagon voltage distribution was 120/208v using 4 sets of network transformers, size varying from 500 kva, 750 kva and 1000 kva, with a total of 21 transformer vaults. 120/208v is very low for such a large building and managing the power distribution of such an imbalance between input and load would require a peculiar and unwieldy arrangement of various sizes and combinations of transformers and switchgears. Under such a scheme, it would have require at least 42 transformer vaults for the new renovated Pentagon. URS Greiner recommended that the voltage be changed to 277/480 v and that 13 vaults and 3 transformers for basement and 10 for 5 wedges, each containing 2,000 kva (4 network transformers), be provided. This scheme allows standard size transformers, switchgears and other controls, resulting in substantial initial and operating cost savings.

The new high voltage distribution system was planned for the Inner Courtyard feeding the new transformers located in B & C rings. This is very difficult to distribute, as well as inefficient and uneconomical. URS Greiner proposed instead an AE Drive routing of the high voltage feeds for distribution to all 10 transformers in wedges very similar to the one which has been serving the Pentagon since 1943. Additionally, a proposed third route for feeder #17 was provided to allow for a more reliable distribution system.

**Emergency Generators and UPS Power System and Distribution** – originally low speed (900 rpm) diesel emergency generators were proposed for the project. Later URS Greiner determined that these generators resulted in excessive initial cost, higher operating and maintenance costs and would require long delivery time to manufacture. URS Greiner proposed using high speed (1800 rpm) diesel emergency generators. These units are more economical, more reliable, and would require less operation and maintenance costs.

Four large 2 mva UPS systems connected in a ring bus arrangement were originally proposed for the basement complex. These units tended to be quite expensive and the ring bus was very difficult to construct in the basement. URS Greiner proposed instead three large, stand-alone, approximately 2 mva UPS systems, one UPS system for each of the three segments in the basement. This resulted in substantial savings in initial and operating costs.

The lack of a wire management system in the existing basement was readily apparent. Work stations are currently fed in various ways: overhead via power poles, under the floor and inside walls and columns. URS Greiner suggested that a raised floor system be constructed in the basement area, with installation of a combined power/communication floor box recessed in the raised floor under the furniture at each work station. Each box would include 4 UPS and 4 normal power outlets, with data/telephone/fiber & video capabilities.

**Supervisory Control and Data Acquisition Systems (SCADA) -** The entire power system is electrically monitored and controlled by a supervisory control and data acquisition system. A series of addressable relays and monitoring devices, with communication modules, is connected to the 15-kv, 480-volt, 120/208-volt, emergency power and UPS systems to provide a complete picture of the electrical system. The master computer control system provides alarms and pre-alarms based on detected system faults, transformer temperatures and a series of status outputs such as amperes, voltage, watt hours, harmonics and power factor. All system parameters can be logged and trended.

One of the successes from the Daniel, Mann, Johnson, & Mendenhall - 3D/International (DMJM-3D/I) Electrical Team was the completion of the electrical short circuit/coordination study. This study consisted of a series of electrical calculations performed for the entire Pentagon Reservation electrical distribution system (EDS). This provided the design basis for electrical equipment selections and protective device setting to ensure the EDS will operate in a safe and reliable manner. Although these calculations are routinely generated for the EDS in the course of individual projects, the performance of the integrated EDS representing a composite of the projects, both ongoing and planned, needed to be examined. The short circuit/coordination study consolidated the information from numerous ongoing projects managed by different firms into one comprehensive electrical study. The results provided confirmation of critical design decisions regarding equipment selection for existing projects and is intended to serve as input data for subsequently planned projects. Cooperation among several A/Es, each responsible for his/her piece of the renovation puzzle, was crucial to the success of the project. The value of open communication among the several A/Es cannot be over emphasized. One such example is of team work is URS Greiner organized a seminar for all the major A/E's working on various phases of Pentagon projects to communicate better with the COE and each other and to coordinate better the tie-ins.

## INFORMATION MANAGEMENT & TELECOMMUNICATIONS

Hand-in-hand with the updated and upgraded electrical systems for the Pentagon is a hub and network for managing critical information and telecommunication requirements. This includes both secure (red) and non secure (black) systems. With the cooperation of the critical military users, the Defense Protective Service, and the Corps with its many design and construction partners, the Army ISC on-site team developed a complete sub-floor and overhead ceiling-accessible distribution and cable management system to facilitate current and future communications requirements

## MECHANICAL SYSTEM

The Central Heating and Refrigeration Plant, was designed by Black and Veatch and included several innovations. First, the completion of a chiller size-selection study early in the project proved to be of benefit. Focusing on a specific chiller size permitted the engineer to complete the design with minimal re-work. In addition, the piping design was able to be completed without the necessity of significant contractor re-work and/or redesign, which would have been the case had the engineer been required to accommodate for chillers of a different size. The chiller manufacturers do not produce units in all sizes. By pre-selecting the chillers based on a comprehensive study, the concerns of the manufacturers could be addressed early in the project, and the design proceeded smoothly to completion.

Having a full time Black & Veatch representative on-site during the construction provided a lower overall project cost to the government. The savings were realized in a reduction in the normal number of construction contractor Requests for Information (RFIs) that had to be sent to the AE's home office for resolution; thereby, minimizing the number of response delays. The on-site representation was able to provide expeditious engineering opinions to the project Resident Engineer, improving overall quality assurance. This approach was so successful it became the model for subsequent projects.

The extensive input provided by the plant operators during both the design and construction stages facilitated smoother commissioning and operator understanding of the new systems. In addition, the operators developed a sense of ownership early in the life of the project. Numerous training and inspection trips to both the chiller and boiler manufacturing plants were arranged by the Corps for the operators to enhance customer satisfaction with the quality and reliability being built into the finished plant.

## METRIFICATION

Plans and specification for the modernization of the Pentagon are being prepared using the metric system in accordance with the Presidential Executive Order mandating the use of metric for all federal government construction projects. In this regard, the Pentagon project poses an unusual challenge. The original design was in the English system, and direct conversion of foot/inch to metric constitutes what is known as ‘soft’ metric. However, the final design is required to be in ‘hard’ metric, which involves rounding, up or down, to the nearest whole millimeter equivalent of soft metric dimension. In effect, a hard metric renovation is being imposed on an existing soft metric core and shell renovation of the Pentagon. Initial construction projects indicate a true success with metric specifications.

## ENERGY

Regarding energy management, the major lesson learned concerns the contribution, or lack of it, to the design cooling load by office equipment. Mechanical engineers design typical offices to about 4.4 W/sf (ASHRAE). They typically use “nameplate” data from the equipment (also called “plug loads” since anything plugged into the wall contributes to cooling needs) and assume it is the cooling contribution (after converting Watts to Btu/hr). However, this information is intended for the Electrical engineer, who has to design wires and electrical systems to carry this load. The problem is that this load is actually very short lived (less than a second in most instances — called the inrush current), and the cooling system/zone never experiences it as a steady-state load. The steady state load is actually less (usually much less — about only 20% of the inrush). So, the erroneous 4.4 W/sf, which is usually increased by each designer who has to use it, and can therefore grow to ridiculous values — is in fact only about 1 W/sf insofar as cooling coil is concerned (0.6 to 1.6 commonly, depending on refrigerators, space heaters used when the AC has been over designed, vending machines, microwaves, and other unique loads). The bottom line is that cooling systems — from the source chillers to DX equipment throughout the air handling system — are designed oversized in error, based upon these exaggerated loads and as a result never really perform properly. The oversized cooling equipment cycles rapidly, resulting in a lack of ability to dehumidify, inability to provide human comfort and never achieves its rated efficiency during short cycles. Occupants become uncomfortable and unhappy. Additionally a fairly significant cost savings is lost in potential decreased sizes of fans, ductwork diffusers, etc. Extensive measurements were taken by our partners from CERL (POC Mr. Larry Lister) to document the actual energy use in heat output from office equipment throughout the building. Measurements were recorded for two days on a data logger and plotted by zone to derive the W/sf, which turned out to be only about 1.0! A more detailed report is in progress. The Buildings Loads Analysis and System Thermodynamics (BLAST) program was used to model both the peak loads (for sizing equipment) and the estimated energy used (electricity and gas, annually) for the new Wedge 1 design. The annual utility bill is about $13 million with the cost of salaries about $1 billion. Productivity of the work force is an important factor as an increase of only 1% in productivity is worth $10 million/year. Thermal comfort has important and obvious, but also hard-to-quantify impacts on productivity, as does the quality of lighting. BLAST computes this data in minute detail, can document the thermal comfort of occupants, predict energy use and support the design decision making process. It also does a great job of determining radiant heat transfer between internal surfaces and handles the sun angles and cooling load impacts on glass surfaces - useful for the window selection issue. A number of national experts were assembled to review the data and provide recommendations for making the renovated Pentagon a very energy efficient building. (*See the report - "Energy Efficient and Environmentally Safe Pentagon").*

URS Greiner prepared an Energy Conservation Study. They looked for ways to optimize the air-side energy consumption for the basement air handlers that would improve on the master plan configuration. Various options and configurations were explored to determine the optimum system selection. At the conclusion of the analysis, a change to packaged, blow through, low temperature, high velocity, VAV systems with variable speed drives was recommended (as opposed to packaged draw-through, normal temperature high-velocity VAV systems with inlet dampers). This change resulted in a 15% energy savings for all air handlers as well as a one size smaller air handler package and smaller truck ductwork.

## SUMMARY OF LESSONS LEARNED AND CRITERIA USED

**Wiring Material** – All wiring is copper including bus bars, windings, panelboards, and switchgears. This results in safer and less maintenance installation. No aluminum wiring is allowed even for temporary construction power.

**Type of Wiring** – All underground low and high voltage wiring is EPR providing for high degree of waterproof installation. Additionally, all lighting fixtures and floor box wiring is flexible and modular allowing flexibility in future changes.

**Grounding Systems -** The entire basement has a signal reference grounding grid for all the data/comm. centers. It provides the best possible grounding system in the computer room.

**Transformers -** Four network transformers will be maintained to allow a reliable system and ease of rebuilding the Pentagon while keeping it operational. Four networks served the Pentagon well since 1943 by providing double redundancy.

**Energy Efficient Systems -** Lighting using T8 lamps and electronic ballasts has been designed and built. Power consumption is less than 10W/square meter (1.0 W/sf). Additionally, energy efficient motors and HVAC systems are provided.

**Lighting Controls -** Local switches and computerize central programmable lighting controls using smart breakers in the panelboards have been installed.

**Emergency Battery Lighting -** 5% of lighting is connected to built-in battery packs in the event of simultaneous failure of normal and emergency power.

**SCADA Systems -** All switchgear H.V. and L.V. gears, breakers, etc. are provided with Automatic Control systems. All breakers, relays and metering are digital and solid state OEM product from the plant.

**Underground Feeders -** Due to short floor to floor heights of only approximately 3.5 meters the amount of circuits that could be put into the overhead ceiling was limited. All of the main low and high voltage feeders were installed underground in the ductbanks. This scheme allowed the construction of HVAC ductwork and cable trays and classified communication in the extremely limited ceiling space.

**Under floor water detection and trench lead detection systems in the entire basement and mechanical trenches -** Provided the under floor water detection systems in the entire basement and mechanical trenches and connected them via autodialer to the automated fire control system located in the building manager's office..

**Relocation of mechanical rooms for more efficient use of floor space -** In basement segment III, two major mechanical rooms were relocated from a more central location as called for in the master plan, to a more perimeter location of the areas they will serve, allowing a more flexible ad efficient use of the tenant space.

**Capture of more tenant space through the creation of a new mechanical mezzanine -** In basement segment II over 7,000 square feet of new tenant space was created by relocating a proposed new mechanical room to a newly created mechanical mezzanine in the corridor nine high bay area.

**Change to low temperature air conditioning system distribution -** Mechanical VAV supply air systems were redesigned to use low temperature supply air for distribution to the tenant space which resulted in smaller air handlers, smaller ductwork and energy savings.

**Change air handlers from draw-through to blow-through configuration to save energy -** Air handlers were redesigned to use a blow-through fan configuration instead of a draw-through configuration which allowed for fan and not heat to be upstream of the cooling coil thereby saving energy and reducing discharge air temperature.

**Reconfiguration of utility tunnels to gain structural cost savings -** The under slab mechanical tunnels were reconfigured to allow for a more shallow tunnel which in turn then required less structural support, resulting in significant cost savings. The additional structural cost for tunnels far outweighs the mechanical design and maintenance problems of trenches.

**Use of a pressurized plenum on air handler supply -** A pressurized supply air plenum was incorporated into the HVAC system design to reduce the air noise transmission to adjacent command center spaces.

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